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硕 士 学 位 论 文

NiZn铁氧体薄膜及[Fe80Ni20-O/NiZn-ferrite]n多层薄膜的制备与研究

Fabrication and Investigation of NiZn-ferrite Thin Films and [Fe80Ni20-O/NiZn-ferrite]n Multilayer Thin Films

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摘　要

随着电子信息技术的迅猛发展，信息的传输速率和处理频率不断提高，电磁元件小型化、集成化与高频化的发展趋势要求应用于电磁元件中的软磁材料具有高的饱和磁化强度、低的矫顽力、高的磁导率、高的自然共振频率和高的电阻率。目前研究较为广泛的高频软磁材料主要是具有高饱和磁化强度以及高磁导率的FeCo及FeNi基合金软磁薄膜材料，这类材料受限于自身的金属特性，通常具有较低的电阻率，这将使其在应用于高频条件下时会产生大的涡流损耗，限制了它在高频领域的应用范围。近年来铁磁性合金与非磁性绝缘介质复合而成的纳米颗粒膜及多层膜能在一定程度上提升软磁薄膜的电阻率，但是非磁性绝缘介质的加入也会降低薄膜的饱和磁化强度。因此进一步研究如何在保持较高饱和磁化强度的条件下提升薄膜的电阻率是十分必要的。NiZn铁氧体是一种具有很高电阻率的亚铁磁性材料，如果用NiZn铁氧体层替代非磁性绝缘介质层制备多层膜，就可以在有效提高薄膜电阻率的同时，增加软磁薄膜的饱和磁化强度，从而可期望获得具有优异高频性能的软磁薄膜材料。本文的主要研究内容及结果如下：

（1）采用磁控溅射方法，在室温条件下制备了一系列具有良好尖晶石结构的NiZn铁氧体薄膜，并系统地研究了溅射功率、溅射气压、氧气流量比$R(O_2)$以及薄膜厚度等制备参数对NiZn铁氧体薄膜的结构和性能的影响，获得了室温条件下有利于提高NiZn铁氧体薄膜结晶性及磁学性能的工艺参数。

（2）研究发现薄膜的整体结晶性越好，晶粒平均尺寸越大，薄膜的饱和磁化强度及矫顽力也就越大。在较高的溅射功率以及较低的溅射气压下，薄膜具有较好的结晶性以及较大的晶粒平均尺寸；在氧气流量比$R(O_2)$小于50%的条件下，薄膜的结晶性随着$R(O_2)$的增大得到了明显的提升。此外，在相同的溅射条件下，随着薄膜厚度的增加，晶粒平均尺寸呈现明显增大的趋势，饱和磁化强度和矫顽力也不断增大。

（3）通过研究基片温度及退火温度对NiZn铁氧体薄膜结构和性能的影响发现，在较高的基片温度下制备出的薄膜具有较大的矫顽力，且薄膜饱和磁化强度随着基片温度的升高而升高；室温下制备出的样品在经退火处理后薄膜矫顽力明显降低，软

磁性能得到很大的改善。

（4）通过研究[Fe80Ni20-O/NiZn-ferrite]n多层软磁薄膜的晶体结构、表面形貌、电学、磁学特性以及高频性能发现，随NiZn铁氧体层的厚度的增加，Fe80Ni20-O薄膜的晶粒明显细化，电阻率大幅度提高，但其饱和磁化强度和静磁导率明显降低。因此，可以通过调节NiZn铁氧体中间层厚度的方法对多层膜的电阻率、饱和磁化强度以及磁导率进行调控。

关键词：NiZn铁氧体；磁学性能；多层薄膜

Abstract

With the rapid development of electronic information technology, the information transmission rate and information processing frequency are improved continuously. The miniaturization, integration and high frequency trends of electromagnetic devices demand the soft-magnetic materials have high saturation magnetization, high permeability, low coercivity, high ferromagnetic resonance frequency and high resistivity. Presently, the FeCo-based and FeNi-based alloys soft-magnetic materials are widely investigated because of their high saturation magnetization and permeability. However, they usually show a low resistivity subjected to their metal characteristics, which will result in high eddy current loss when they are working in high frequency condition. Therefore, the application of FeCo-base and FeNi-base soft magnetic materials into high frequency condition is limited. The nanogranular films and multilayer films composed of ferromagnetic alloys and non-magnetic insulating medium can promote the resistivity in some degree, but the addition of the non-magnetic insulating medium will result in a decrease of the saturation magnetization. Therefore, it is of great importance to further investigate how to promote the resistivity of soft-magnetic films under the condition of maintaining a relative high saturation magnetization. NiZn-ferrite is a kind of ferrimagnetic materials with large resistivity, so we can prepare multilayer films in which the non-magnetic insulating dielectric layers are replaced by NiZn-ferrite layers. In this case, we can promote the resistivity and saturation magnetization of the thin films simultaneously, thus the multilayer thin films can exhibit excellent high-frequency performance.

The main contents and results of this paper were outlined as following:

(1) The NiZn-ferrite films with well-defined spinel structure were successfully prepared by magnetron sputtering at room temperature. In order to obtain the room temperature preparing process which can promote the crystallinity and

magnetic properties of NiZn-ferrite films, the effects of sputtering power, sputtering pressure, the relative oxygen flow ratio R(O2) and film thickness on the structure and properties of NiZn-ferrite films were investigated.

(2) The study found that the NiZn-ferrite films with better crystallinity and larger grain size would show higher saturation magnetization and larger coercivity. High sputtering power and low sputtering pressure were beneficial for the crystallization and grain growth of NiZn-ferrite films. The crystallization of the films was improved rapidly with the increase of R(O2) when R(O2) is less than 50%. Besides that, under the same sputtering condition, films with higher thickness exhibited larger grain size.

(3) The effects of substrate temperature and annealing temperature on the structure and properties of NiZn-ferrite films were investigated. The study found that the films deposited under high substrate temperature show a large coercivity, and the saturation magnetization increased with the increasing of substrate temperature. Annealing treatment could significantly reduce the coercivity of the films prepared under room temperature and promte the soft-magnetic properties of the films.

(4) The crystal structure, surface morphology, electrical property, magnetic property and high frequency performance of [Fe80Ni20-O/NiZn-ferrite]n multilayer films were investigated. It was found that with the increasing of NiZn-ferrite layer thickness, the grain of Fe80Ni20-O layer was refined obviously, and the resistivity of the multilayer thin films were greatly improved, but the saturation magnetization and high frequency permeability were reduced at the same time. Therefore, we could adjust the resistivity, saturation magnetization and high frequency permeability of the multilayer films by changing the NiZn-ferrite layer thickness.

Keywords: NiZn-ferrite; Magnetic properties; Multilayer films

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